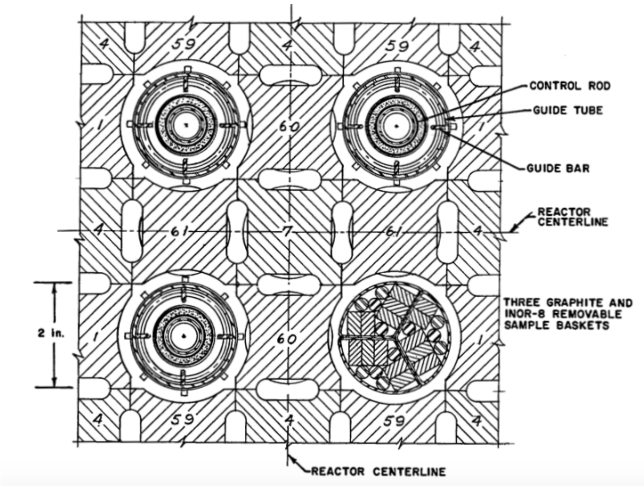

Criticality benchmark of the Molten Salt Reactor Experiment

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Molten Salt Reactor Workshop 2017 | Key Technology and Safety Issues for MSRs

October 3, 2017

A peer-reviewed reactor physics benchmark for molten salt technologies is under development

- DOE NE awarded an NEUP to UC Berkeley, in collaboration with ORNL and the Grenoble Institute of Technology (France), to create an MSRE benchmark (October 2016)

- The target is to create a benchmark for the International Reactor Physics Benchmark Experiment Evaluation Project (IRPhEP) handbook
  - peer-reviewed set of reactor physics-related integral data
  - used by reactor designers to validate analytical tools for advanced reactors
  - used by safety analysts to establish the safety basis for operation of advanced reactors

The benchmark is based on a series of start-up zero-power experiments (June 1965)

- An initial criticality experiment measured the minimum amount of ^{235}U needed to reach criticality
- Measurements of the differential worth of one control rod as a function of position with stationary and circulating salt
- Measurements of the integral worth of various control rod configurations
- Criticality configurations obtained changing ^{235}U concentration and control rod positions;
- Measurements with stationary and circulating salt conditions
- Measurement of the whole core isothermal temperature reactivity coefficient
- Measurement of the pressure reactivity coefficient

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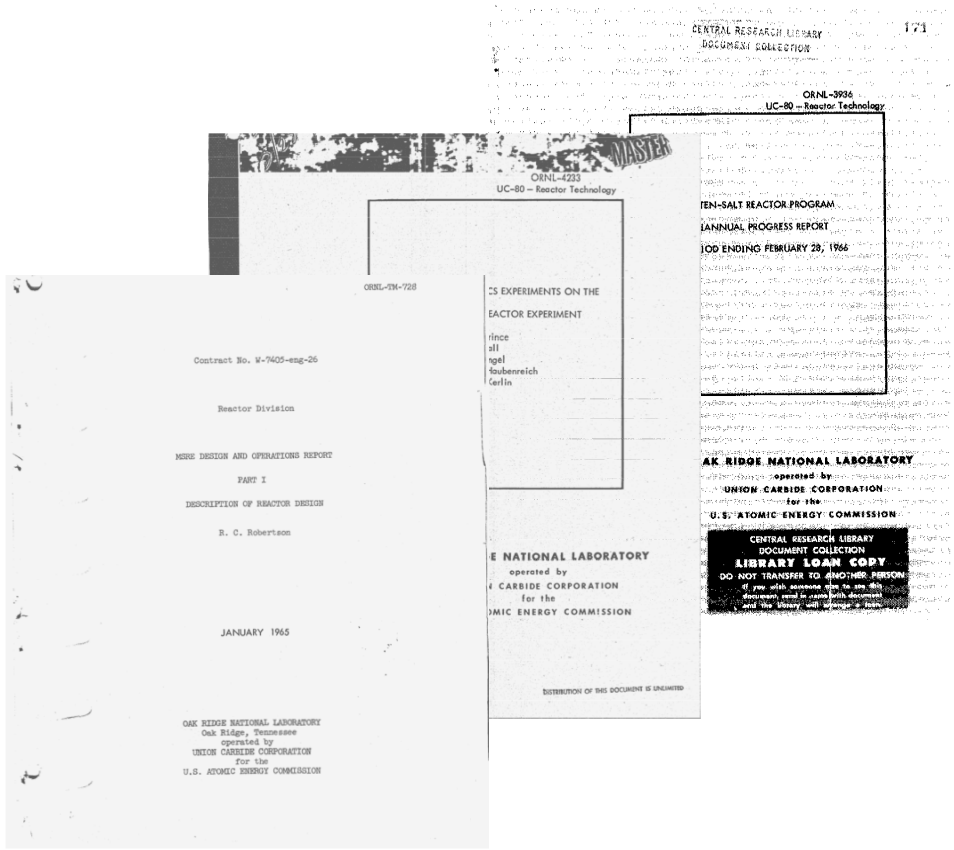
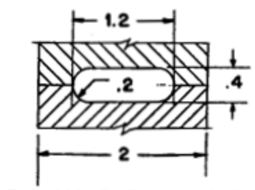
Creating a benchmark consists of two main tasks

- Create benchmark specifications
  - Retrieve data and related uncertainty
  - Make assumptions as needed
- Test the benchmark
  - Create and run one or more computational models
  - Assess uncertainties



Fuel geometry



TYPICAL FUEL PASSAGE

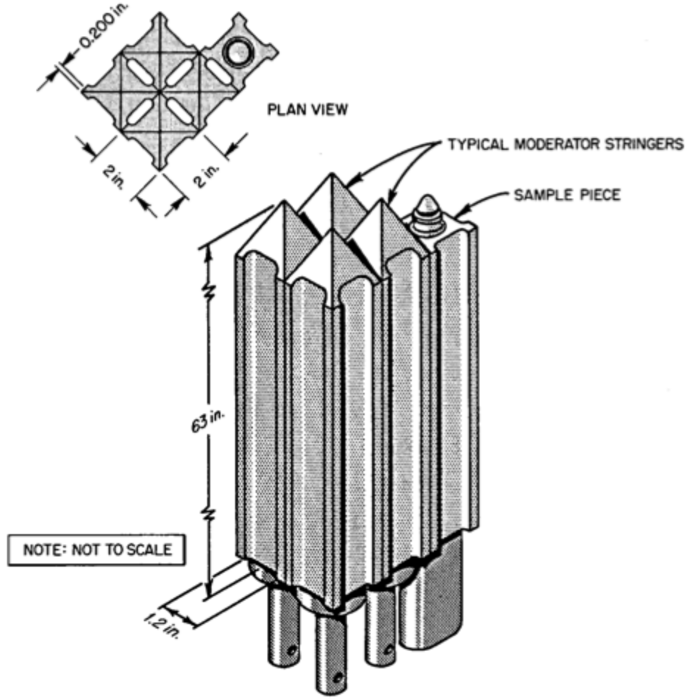
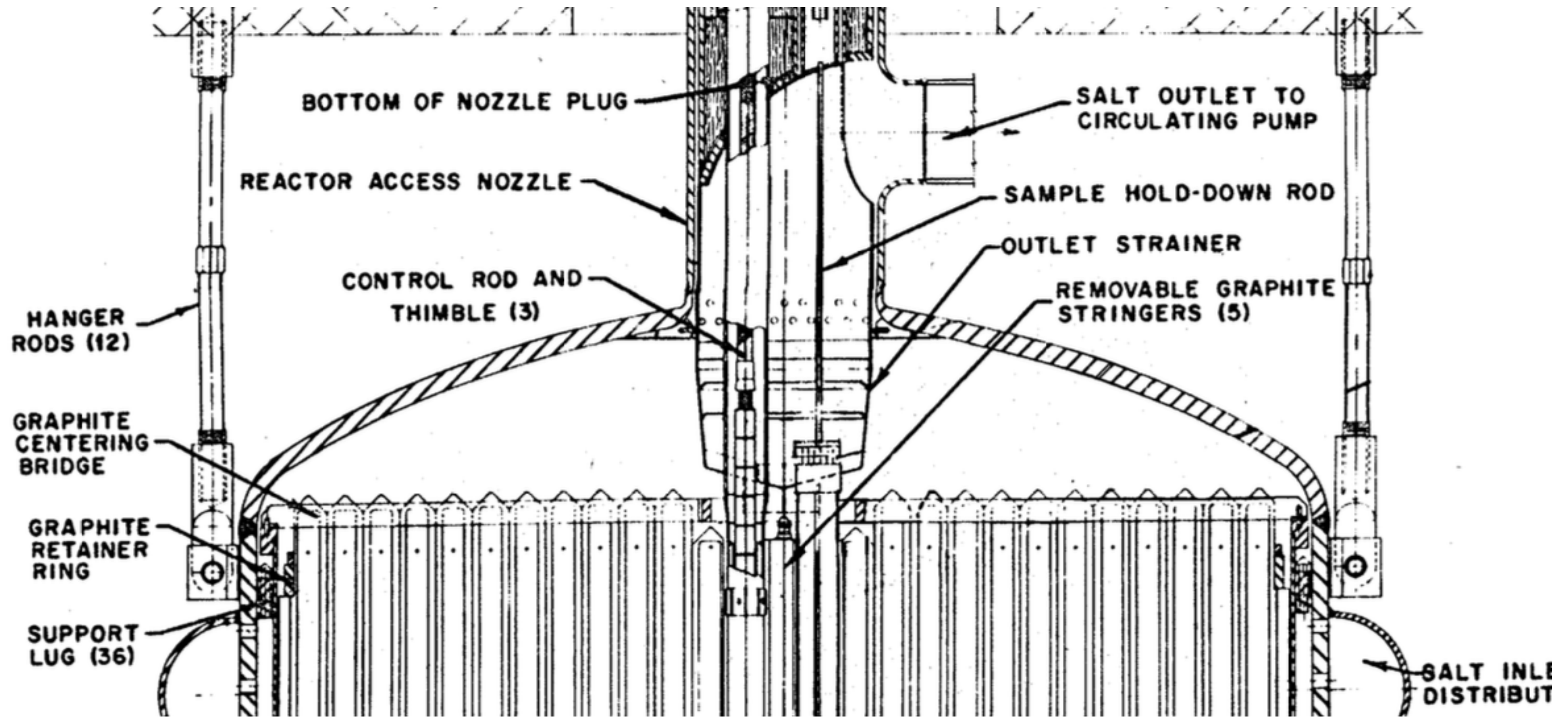
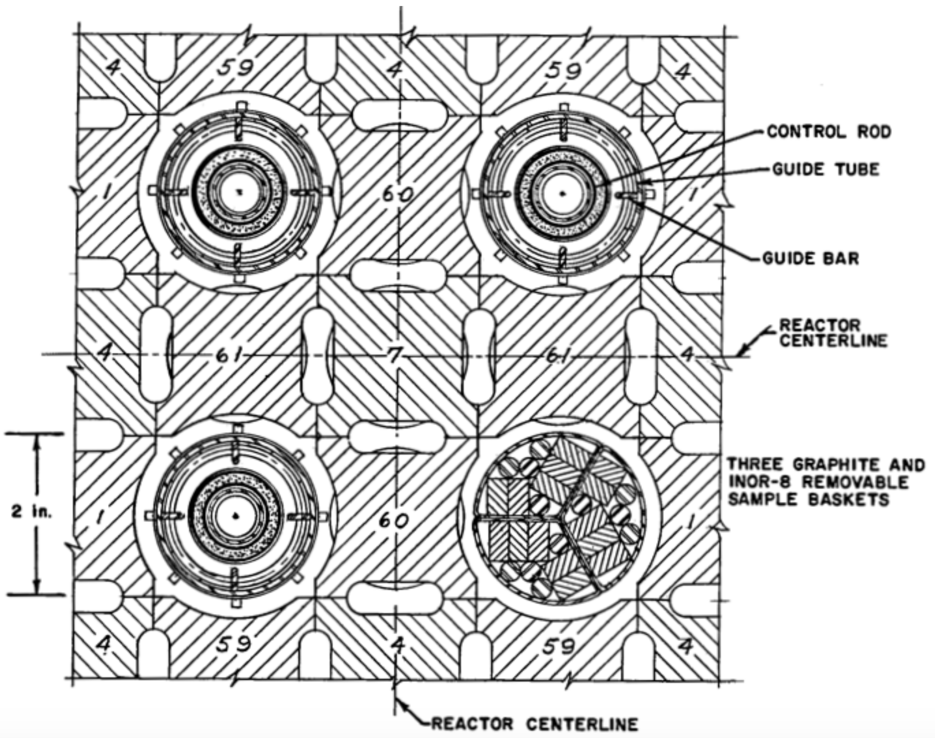


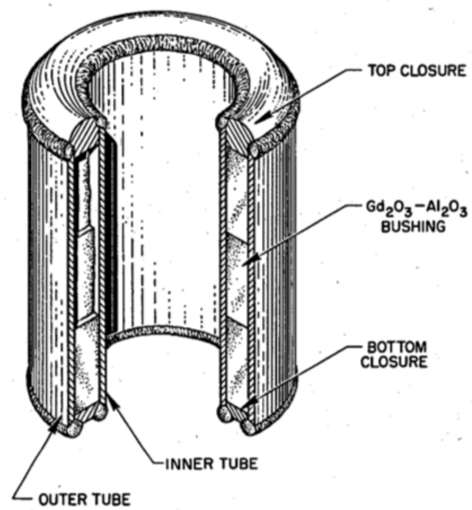
FIG. 5.6.
TYPICAL GRAPHITE STRINGER ARRANGEMENT

Top components



Control rods and sample baskets





Unclassified
ORNL DWG 64-8816

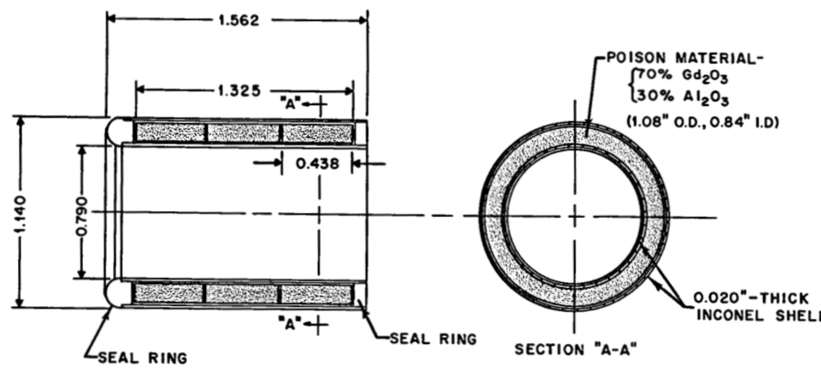
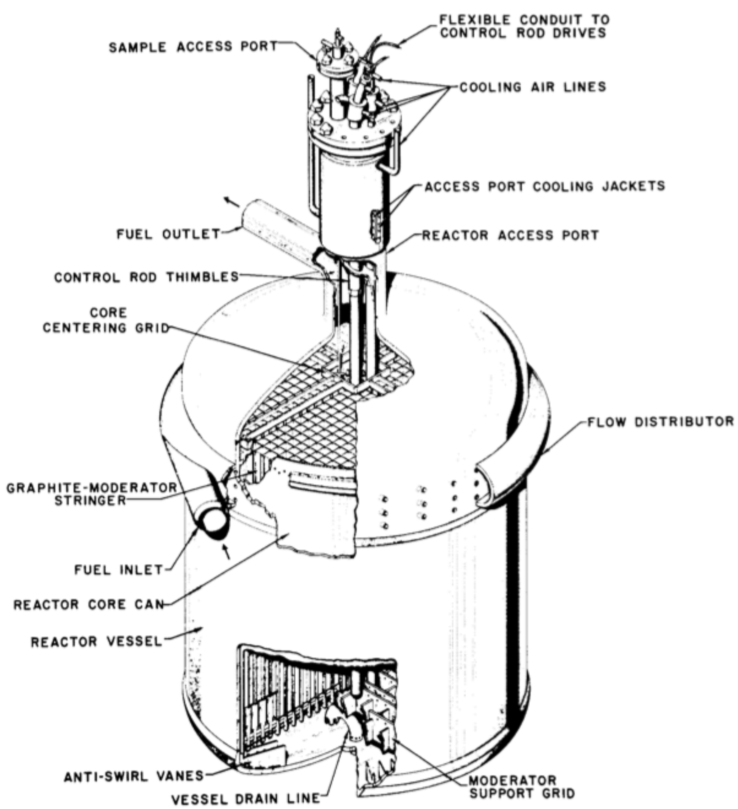


Fig. 5.13. Control Rod Poison Element.

Outer core components



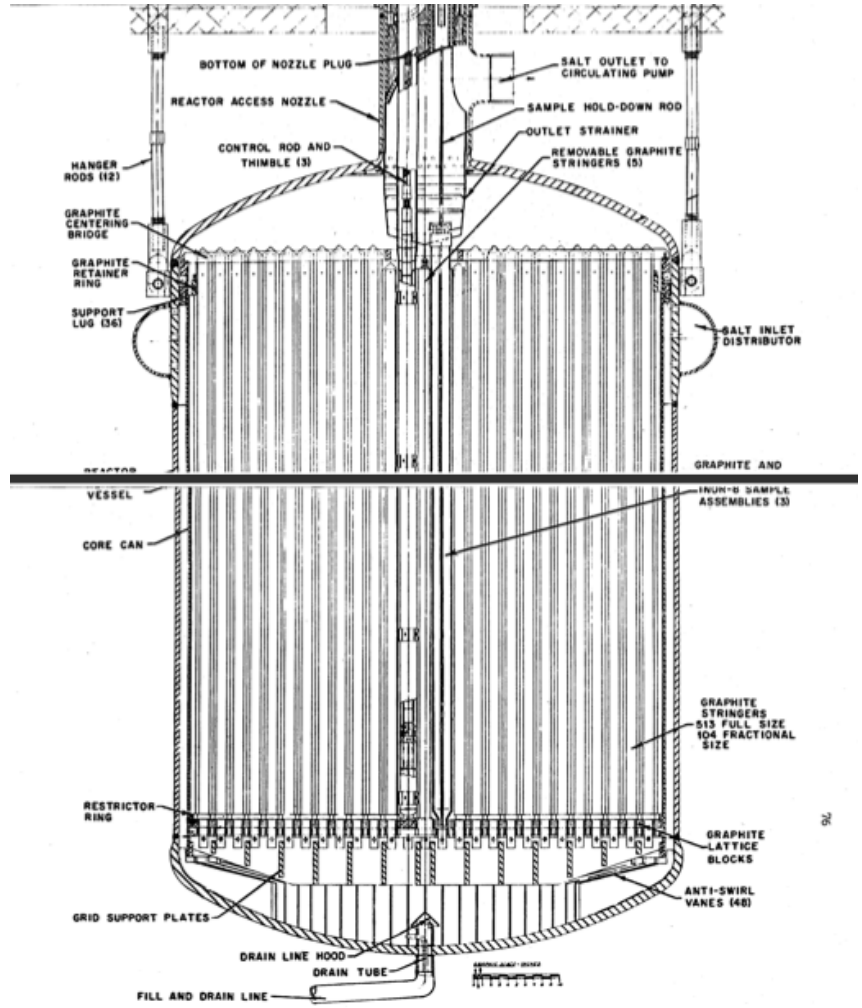
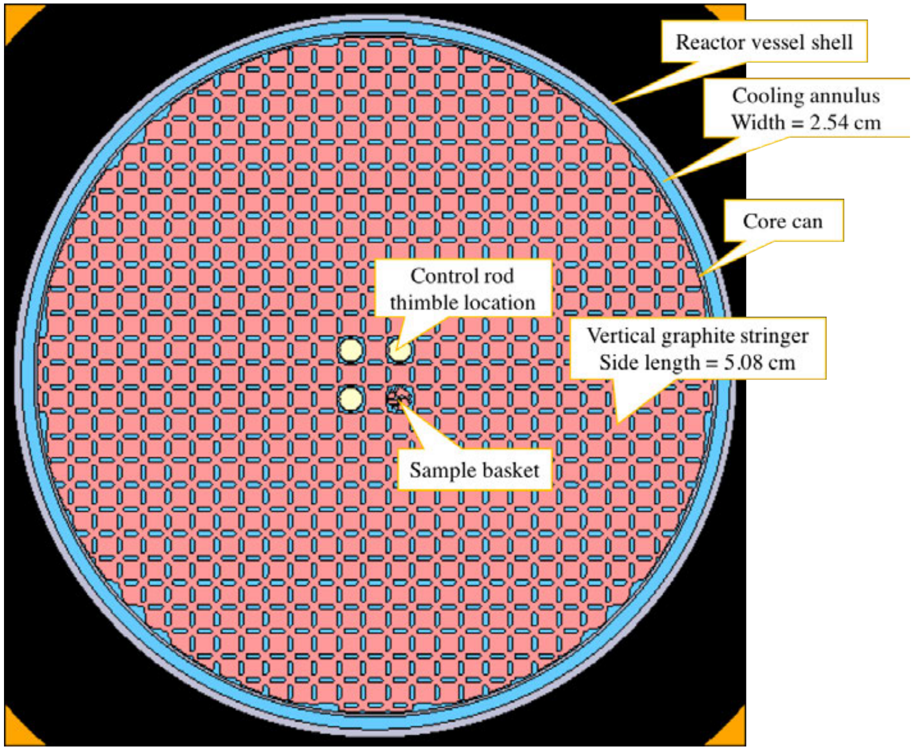


Fig. 5.4.
CROSS SECTION
MSRE REACTOR VESSEL AND ACCESS NOZZLE

Core model



Horizontal cross section of the MSRE model

Dowel section of graphite lattice

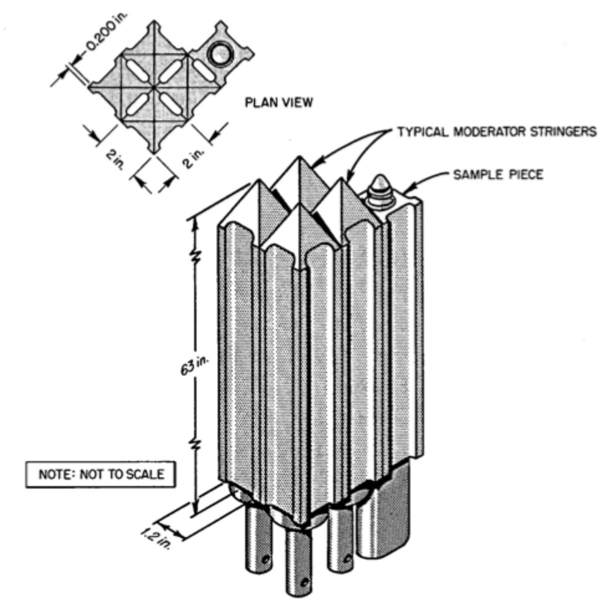
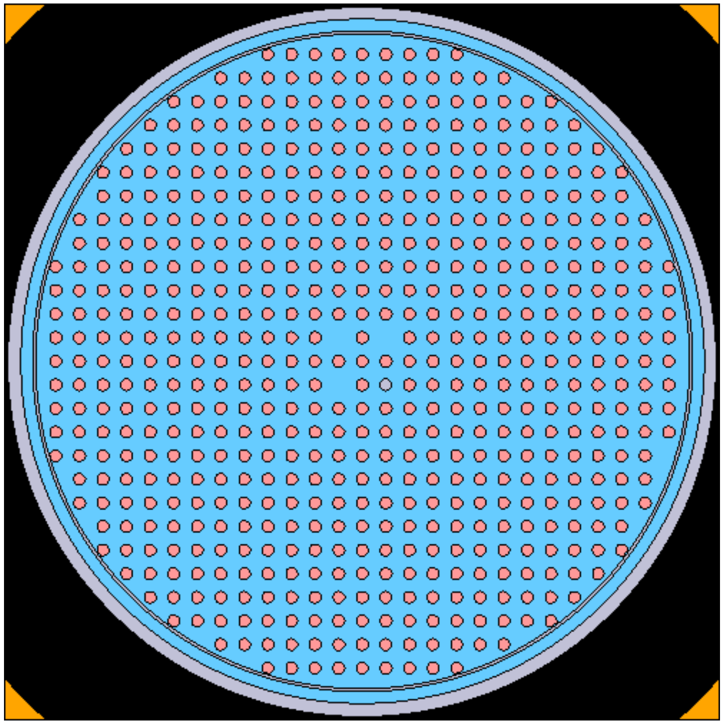
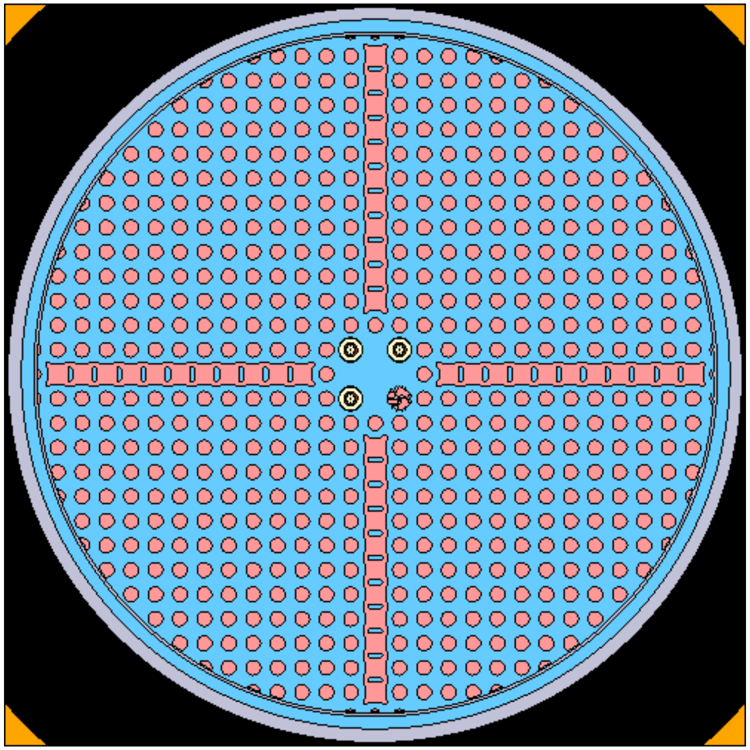


FIG. 5.6.
TYPICAL GRAPHITE STRINGER
ARRANGEMENT



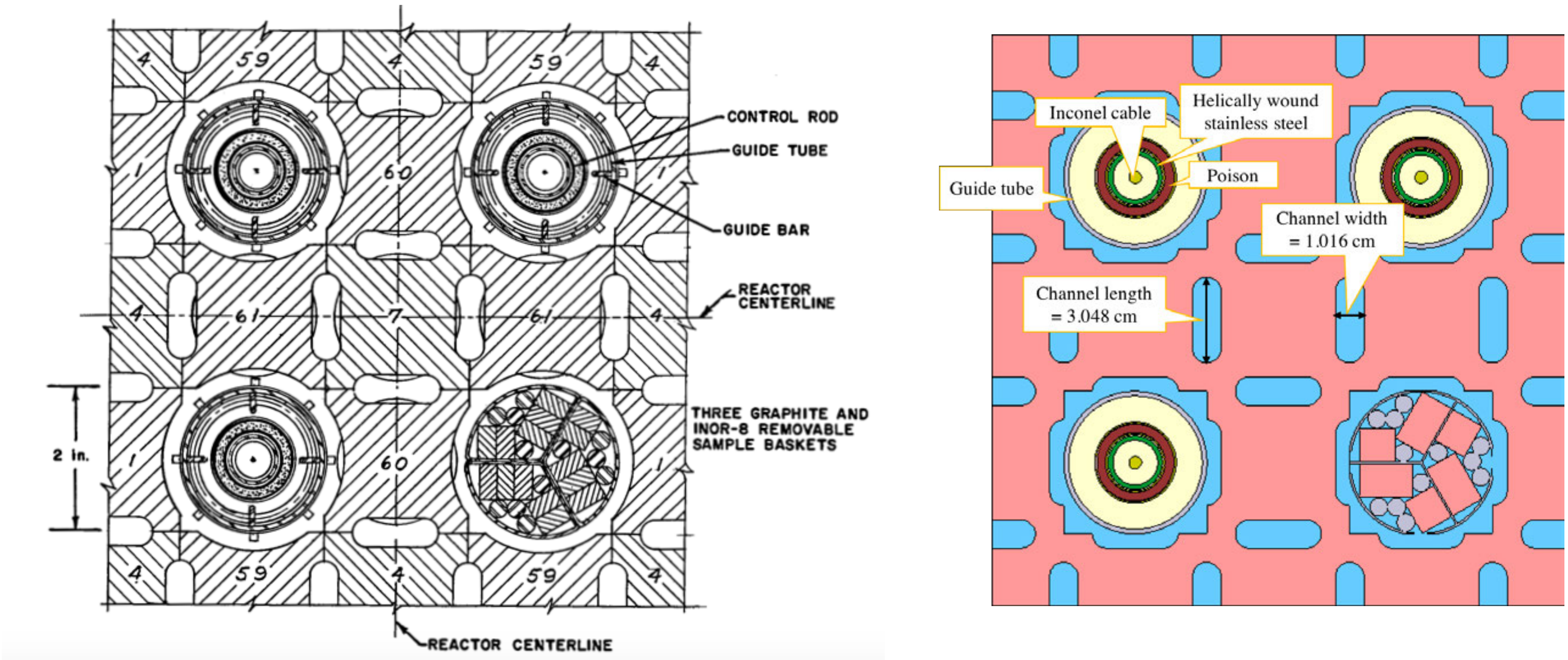
Horizontal cross section of the dowel section of the graphite lattice

Taper region



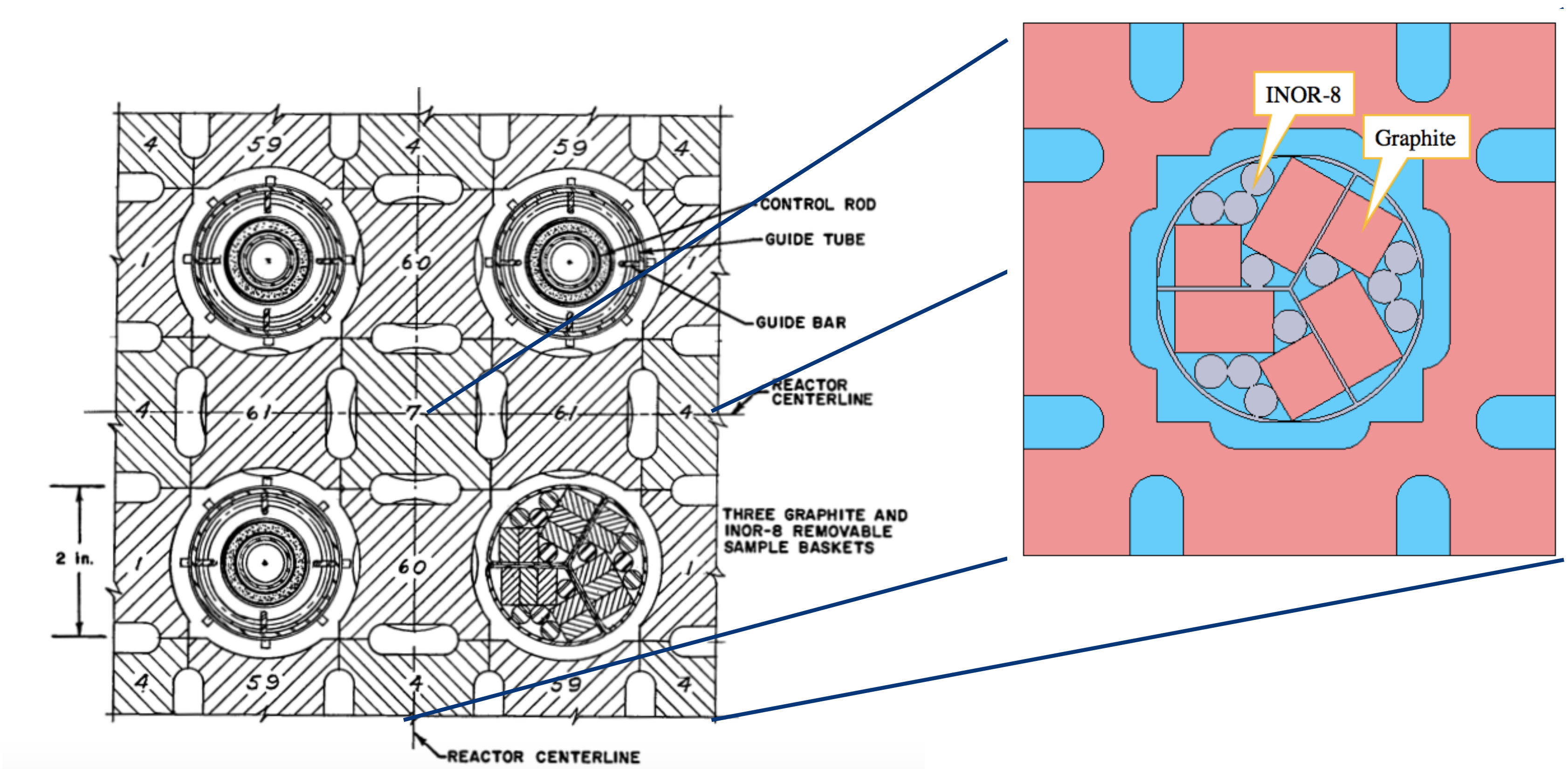
Horizontal cross section of the taper region

Control rods and sample baskets

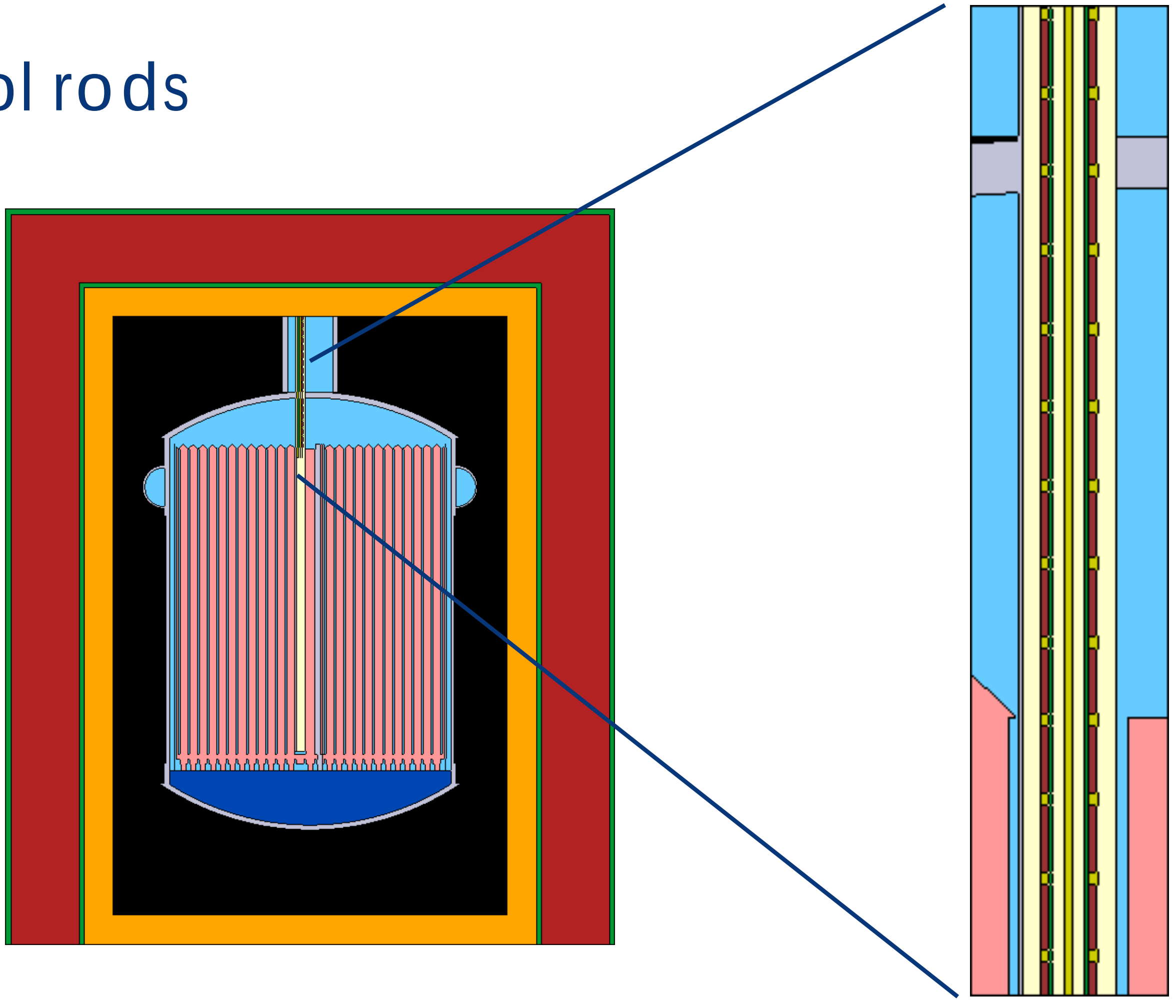


Horizontal cross section of the control rods and sample baskets

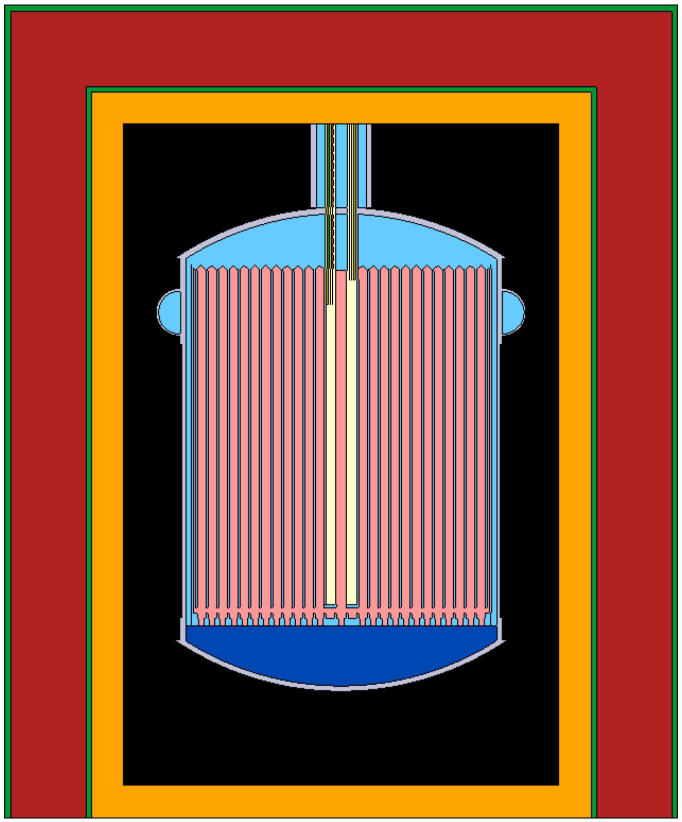
Sample baskets

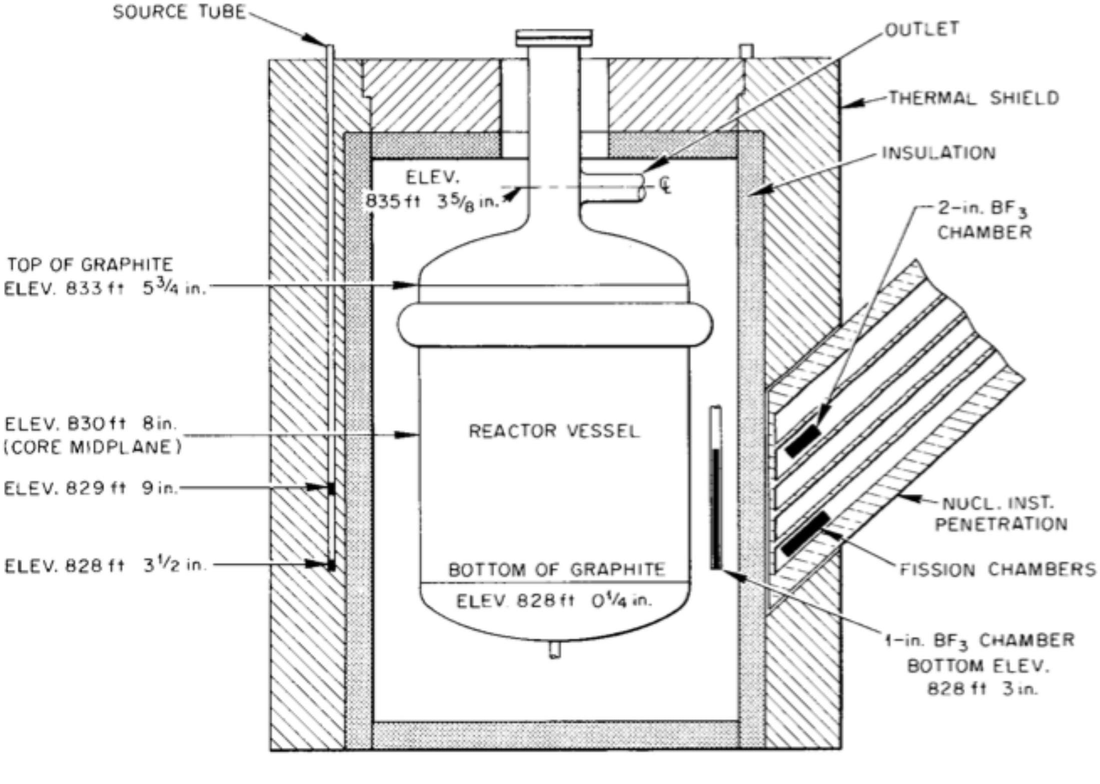


Control rods



Overall model





ELEVATION

The benchmark model was tested on the first MSRE criticality experiment

- Fuel salt composition 65LiF-29.2BeF_2-5ZrF_4-0.8UF_4 (99.99% for ^{7}Li enrichment).
- Fuel salt density 145.3 ± 1.0 lb/ft^3 (2.3275 ± 0.0160 g/cm^3)
- Mass fraction of ^{235}U in the salt is 1.408 ± 0.007 wt%
- Core temperature 1,181°F (638°C)
- One rod was inserted at 46.6 in. position, other two rods at their upper limits

Case	k_{eff}	100(C-E)/E
Benchmark	1.0	-
Calculated (SERPENT2, ENDF/B-VII.1 cross sections)	1.01276 ± 0.000098	1.276

Graphite density is the major source of uncertainties on k_{eff}

Item	Nominal and bounding values	$\|\Delta k\| \times 10^{-5}$
Graphite density	(1.87±0.02) g/cm^3	349
Fuel salt density	(2.3275±0.0160) g/cm^3	83
^{235}U mass fraction in the salt	(1.408±0.007) wt%	61
INOR-8 density	(8.7745±0.0200) g/cm^3	9
Graphite core height	(166.446±1) cm	19
Graphite core radius	(70.168±0.2) cm	13
Fuel channel width	(1.016±0.127) cm	100
Fuel channel length	(3.048±0.127) cm	42
^{6}Li enrichment	(0.01± 0.001) at. %	174
Boron concentration in graphite	(0.00008±0.000008) wt. %	18
Outlet pipe height	39.687 cm (1σ = 4 cm)	31
Distributor thickness	0.819 cm (1σ = 0.08 cm)	29
Sample basket shell dimension	remove one INOR-8 plate	16
INOR-8 composition	0.06% (C mass fraction), 0.08%	10
Total (root mean square)		422

The largest sensitivity coefficients for k_{eff} from cross section data uncertainties are for C and ^{235}U

Nuclide	Total	Elastic scattering	Disappearance	Fission
Li-6	-0.0286	0.0000	-0.0286	-
Li-7	0.0040	0.0165	-0.0139	-
Be-9	0.0251	0.0283	-0.0033	-
Zr-90	0.0014	0.0018	-0.0006	-
Zr-91	-0.0060	0.0005	-0.0066	-
Zr-92	-0.0007	0.0008	-0.0016	-
Zr-94	-0.0002	0.0001	-0.0005	-
Zr-96	-0.0006	0.0002	-0.0008	-
F-19	0.0749	0.0705	-0.0105	-
C-nat	0.5212	0.3970	-0.018	-
B-10	-0.0064	0.0000	-0.0064	-
U-235	0.2386	0.0003	-0.1386	0.3768
U-238	-0.0857	0.0056	-0.0921	0.0006

Conclusions

- A set of benchmarks based on the MSRE is under development
- The evaluations will include multiple benchmarks following the zero-power experiments campaign of June 1965
- A draft benchmark of the first criticality obtained varying ^{235}U concentration with steady salt is under review for inclusion in the Reactor Physics Benchmark Experiment Evaluation Project (IRPhEP) Handbook
- If you are interested in the draft benchmark email us: maxfratoni@berkeley.edu

Acknowledgements

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External reviewer

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Jozef Stefan Institute, Slovenia

NEUP Nuclear Energy University Programs
U.S. Department of Energy

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